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Kumpulainen, Kristiina

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Researching the Materiality of Communication in an Educational Makerspace: The Meaning of Social Objects

Kristiina Kumpulainen, Antti Rajala and Anu Kajamaa, University of Helsinki

Corresponding author:
Kristiina Kumpulainen
Faculty of Educational Sciences
Siltavuorenpenger 5A
FI-00014 University of Helsinki
Finland
GSM: +358 50 3185221
email: kristiina.kumpulainen@helsinki.fi

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Abstract

This chapter focuses on researching and understanding the meaning and role of materiality in students' and their teachers' communication in a novel educational makerspace. Makerspaces have recently attracted educational attention as sites of student-driven learning in which participants use traditional and novel digital artefacts, such as 3D-printers, electronics and design apps in their engagement with personally meaningful design projects. Drawing on Vygotsky's sociocultural theory, the Bakhtinian inspired notion of the 'dialogic space' and material-discursive onto-epistemology, the chapter introduces the concept of 'social object' to explain how material objects are socialised in ongoing communication, creating opportunities and tensions for learning and teaching in educational makerspaces.

Keywords: makerspace, materiality, dialogic space, social objects, teaching and learning

Researching the Materiality of Communication in an Educational Makerspace: The Meaning of Social Objects

Recent cultural, technological and pedagogical developments have resulted in major reconfigurations of the materialities of educational settings. Many schools are being equipped with novel digital tools and applications to address contemporary learning requirements and pedagogical approaches (Voogt, Knezek, Christensen, & Lai, 2018). Not only are these new materialities entangled with teaching and learning processes, they can also extend and connect educational activities to the everyday lives of students and their communities outside the school, creating hybrid communication spaces for teaching and learning in which the everyday and formal funds of knowledge can vividly intersect (Kumpulainen, Mikkola, & Rajala, 2018; Kajamaa, Kumpulainen, & Rajala, in press). Further, recent technological infrastructures and their learning arrangements allow students to relate to materiality in new ways. In these novel socio-material configurations, students are typically invited to act creatively to modify and develop material objects as part of the learning process. Hence, the materiality itself is in transformation through student agency (Kumpulainen, Kajamaa, & Rajala, 2018). Relatedly, the actual physical spaces of schools are being transformed into more open and flexible spaces amplified with novel furnishings to support learner-centred pedagogies, serving diverse students and their needs (Daniels, Tse, Stables, & Cox, 2018).

As the result of the new educational materialities, a number of researchers have called for a more nuanced conceptualisation and empirical operationalisation of materiality in communication, learning and education (Fenwick & Landri, 2017; Hetherington & Wegerif, 2018; Kuby & Roswell, 2017). At the same time the post-human and socio-material approaches have begun to challenge the more dominant dualistic thinking that typically regards materials,

humans and the natural world as separate entities. This so called 'material turn' rests on relational ontology (e.g., Barad, 2007; Bennett, 2010; Braidotti, 2010; Deleuze and Guattari, 1994; Taylor, 2016) that holds that humans, non-humans (i.e., material objects) and more-than-humans (i.e., natural world/nature) are entangled and intra-acting and, hence, mutually constitutive of each other with no clear boundaries. Furthermore, this conceptualising attempts to move away from a representational approach in which language and communicative action have typically played a central role towards a performative approach that holds that truths, realities, knowledges, relationships, literacies, agency and identities are performed in and through material-discursive practices (Kuby & Roswell, 2017). However, it is acknowledged that the actual empirical operationalisation of the new material turn in educational research warrants more attention and development. Similarly, the implications of this approach for informing educational practice and design deserve further inquiry.

In this chapter, we are motivated to contribute to current theorising and empirical research on the materiality of communication in a novel technology-rich educational setting called a 'makerspace'. Educational makerspaces prescribe a constructionist model of learner-centred pedagogies in which students can work on personally meaningful design projects and where they can make choices about their activities while simultaneously navigating several fields of knowledge and using novel materialialities, such as 3D printers, electronics, programming software and digital applications that enable them to externalize, share and build ideas into concrete material objects (Halverson & Sheridan, 2014; Honey & Kanter, 2013; Marsh, et al., 2017; Peppler, Halverson, & Kafai, 2016). Makerspaces are regarded to hold educational potential to foster students' agency, persistence, creative problem-solving, digital literacy, STEAM (science, technology, engineering, arts and mathematics) learning and 21st century

skills (see e.g., Honey & Kanter, 2013; Kafai, Fields, & Searle, 2014; Lindtner, 2014; Martinez & Stager, 2013). In sum, makerspaces account for a complex set of materially mediated activities that encompass not only processes of creating specific material objects supported by a wide range of technologies and media, but also emotional, relational and cultural processes surrounding the use and construction of material objects (Kumpulainen, 2017).

In formal education as in any other culturally situated practices, there are normative expectations about how and to what ends cultural artefacts are used (Säljö, 2010). In the context of makerspaces, these educational expectations and goals are somewhat alternative to the traditional models of knowledge transmission, towards student agency, knowledge creation and creativity (Kumpulainen, Kajamaa, & Rajala, 2018). That is, educational makerspaces hold normative values that are typically to do with positioning students as active 'makers' who are able, willing and competent to design and create new solutions for their personal and/or collective needs with the available material objects. These values and the educational goals of the makerspace typically target creating the next generation of STEAM workforce with an entrepreneurial, creative and collaborative mind-set (Halverson & Sheridan, 2014). Material objects and materiality in general in educational processes are closely intertwined with power, politics and ideology (Knorr-Cetina, 1997), and hence urge more research attention at least from the perspectives of educational equity and educational change.

We are interested in investigating how the materialities of an educational makerspace mediate the communication processes among students and their teachers during their design and making activities. By material objects, we refer to both natural and man-made artefacts that are available in the educational makerspace, including various technologies, such as laptops,

computers, 3D printers, electronics, robotics, and digital applications and software for design that students can freely choose to use based on their interests and self-selected design projects.

To understand the mediational role of artefacts in educational makerspaces, our work draws on the notion of the 'social object' that explains how material objects can turn into a joint focus of attention and meaning making between students and teachers—similar to artefacts in a museum that spark conversation between people. In our conceptualising, we do not automatically view artefacts as social until they are integrated and taken up in communication and joint activity. We consider social objects as transactional, facilitating exchanges among those who encounter them (Knorr-Cetina, 1997; Simon, 2010). To this end, we ask how material objects of the educational makerspace turn into social objects in communication among students and their teachers and how social objects mediate the communication processes of teaching and learning in the educational makerspace.

Theorising the Meaning and the Role of Materiality in Educational Makerspaces

Our research work on the materiality of communication in a novel educational makerspace draws upon sociocultural theorising regarding tool-mediation (Vygotsky, 1986, 1997; Wertsch, 1991, 2002), the Bakhtinian inspired notion of the 'dialogic space' (Bakhtin, 1986; Wegerif, 2011), and material-discursive onto-epistemology proposed by Barad (2003, 2007). We suggest that regardless of their different starting points, the body of conceptual knowledge these theoretical approaches have generated offer a promising complementary approach for extending and empirically operationalising the meaning and role of materiality—with a specific attention to social objects—in and for teaching and learning in novel educational makerspaces.

The sociocultural theorising underscores the historicity of human activity and material objects (Cole, 1996). Each material object has a history in the socio-genesis of a particular social practice. Material objects carry with them cultural knowledge both for the individual and for the collective about their history, purpose and use, including values and ideologies. Material objects can also act as mediational means for personal and/or collective remembering (Wertsch, 2002). Hence, for the sociocultural approach, it is important to understand human behaviour in the contexts of interdependent and ever-changing material-discursive spaces grounded in history. Similarly, in our work, material objects, when turned into social objects, are regarded as having their own voice(s) that carry with them cultural knowledge (Säljö, 2010; Wertsch, 2002). It is all these voices that together mediate the communication processes in educational makerspaces.

In his seminal work on tool-mediation, Vygotsky and his co-investigators analysed how humans transform the environment in which they live through tool-mediated activities (Vygotsky 1986; Vygotsky & Luria 1994). They saw material-semiotic tools as constitutive of human activity and a prominent driving force for the development of human mind and culture (Vygotsky, 1986, 1997). For Vygotsky, language was the tool of tools; however, he did not undermine the mediational role of tangible objects (i.e., material tools or artefacts) for human learning and development. In fact, the centrality of materiality in human activity advocated by sociocultural theorising reminds us of how social action and semiotic tools (both tangible and conceptual) are intertwined (see also Ingold, 2010; Mäkitalo, 2011).

To further define Vygotsky's theory of 'tool-mediation', Wertsch (2007) proposes a distinction between *explicit* and *implicit* mediation. For him, explicit mediation refers to the intentional process of introducing a 'stimulus means' into an ongoing activity to overcome and potentially transform existing challenges or limitations. In explicit mediation, intention is overt,

and the materiality as a stimulus means is 'obvious and non-transitory' (Wertsch 2007, p. 180). Implicit mediation involves signs, especially language, that are brought into the stream of joint activity as part of evolving joint action and communication. In implicit mediation, the material-semiotic tool is often less obvious than in explicit mediation, and hence less easily taken up for joint attention and reflection. In our work, we are interested in empirically grasping the dynamics of explicit and implicit mediation in the communication among students, teachers, and the material objects in the context of the educational makerspace. In particular, we are interested in how material objects—whether explicitly or implicitly taken up in student activity—turn into and function as 'social objects' in the material-dialogic spaces of communication to which the participants orient themselves in joint activity and the opportunities and tensions of these material-discursive spaces of communication for teaching and learning in an educational makerspace.

The dialogic space has been defined in the literature as a specific communicative event that evidences exploration, problematisation and elaboration of diverse views and understanding in reasoned dialogue (Wegerif, 2008; Mercer et al., 2010). In following the new material turn, we propose that a material-discursive emphasis can be used to extend the original dialogic account of the production of meaning in a way that it refocuses attention on the 'voices' of the material in co-mediating teaching and learning in educational makerspaces (see also Hetherington & Wegerif, 2018).

In Barad's (2003, 2007) material-discursive onto-epistemology, matter is an active participant in the performance of phenomena. There is no separation between matter and meaning but a single entangled reality in which humans and materials intra-act, making a difference in the activity, and to its consequences and outcomes. These intra-actions and

resulting performances, to which both people and materials contribute co-create material-dialogic spaces with consequences to ontological, epistemic, social, and ideological/political processes. Consequently, in our work, the material-dialogic space of communication accounts for an intra-acting space of possibilities in which the voices of the materialities, humans, and more than humans intra-act and perform particular teaching and learning arrangements. Here the dialogic space overlaps with the material and physical, the material objects acting in varied roles and meanings in relation to social activity. It is these material-dialogic spaces that our research aims to examine with a specific interest on the meaning and role of materiality in a novel educational makerspace.

Empirical Study

The empirical data of our research stems from a Finnish city-run comprehensive school with 535 students and 28 teachers at the primary level. Like any other school in Finland, this school follows the national core curriculum, which has been defined locally. The local curriculum of the school stresses design learning, which is considered to enhance students' creative problem-solving skills across the curriculum. The school strives for learner-centeredness and for innovations in learning and teaching and is committed to following the principles of progressive inquiry in its pedagogy (as expressed in its local curriculum document of 2016).[1] As a response, the school has recently (in autumn 2016) introduced a new educational makerspace, the FUSE Studio (www.fusestudio.net) as part of its elective courses as a means of enhancing interest-driven, student-centred, empowering, collective and inclusive learning.

FUSE Studio

The FUSE Studio is an educational makerspace, 'a choice-based digital infrastructure for STEAM learning' (Stevens & Jona, 2017). The technological infrastructure of the FUSE Studio

offers students different STEAM challenges that 'level up' in difficulty like video games. The challenges include *Spaghetti Structures*, *Jewellery Designer, Robot Obstacle Course, Keychain Customiser, Electric Apparel, Coaster Boss* and *Solar Roller.* The challenges are accompanied by various tools, such as computers, 3D printers and other materials (e.g., foam rubber, marbles, tape and scissors), as well as instructions for how to process the challenges (see Figure 1).

Insert Figure 1 here

Figure 1. Students working on the FUSE Studio maker challenges

Each FUSE maker challenge is designed to engage students in different STEAM topics and skill sets. The challenges have been carefully structured to introduce students to new ideas and to support them through more complex iterations of those ideas. Students can choose, based on their own interests, which challenges they want to work on, when and with whom. They can choose to work alone or with peers. There is no formal grading or assessment by teachers. Instead, using photos, videos or other digital artefacts, students can document their completion of a challenge, and the completion unlocks the next challenge in a sequence.

Methods

The primary data of this study is comprised of 75 hours of video recordings of students aged between 9 and 12 years (N = 94) carrying out design activities in the FUSE Studio makerspace. The recordings were collected intermittently every week over a period of one semester. The videos were filmed by a team of researchers that included four master-level students and three university researchers. The research group had four cameras in total. Depending on how many researchers were available to film the lessons on given days, two to four cameras were filming at once. Generally, half of the cameras were filming teachers and half

focused on students working in the makerspace. Wireless microphones were attached to the video cameras to record oral communication between the students and teachers. The students' activities on the computer screens were also video-recorded, whenever it was deemed a part of the problem solving or communication.

The data come from three different groups of students and their teachers who participated in the FUSE Studio elective course. Due to the elective nature of the course, the groups consisted of students from several classes. Group 1 consisted of 32 students (22 boys and 10 girls), Group 2 consisted of 30 students (19 boys and 11 girls) and Group 3 consisted of 32 students (19 boys and 13 girls). Each group was supported by two to four teachers and teaching assistants. At the beginning, each group had one 45-minute FUSE session a week, but later, sessions were extended to 60 minutes.

Each student group was assigned a teacher in charge, but other teachers and teaching assistants worked in the groups as well. Altogether, the school had six male and two female teachers who ran the FUSE makerspaces. The teachers had participated in a two-day FUSE training provided by members of the FUSE team from the United States. The teachers were presented the opportunity to partake in the training according to their own interests in the field of innovative STEAM learning.

The FUSE Studio was situated in the school's computer lab, a neighbouring classroom space, and the nearby hallway. In the computer lab, there were 22 desktop computers and separate laptops. The students could freely choose where they wanted to work and whether they wanted to work alone, in pairs or in small groups. The choice often depended on which design challenge the student was interested in working with. For example, the *Dream Home* challenge was often realised individually by the students, whereas the *Coaster Boss* practically required

teamwork due to the construction work with the material objects. Since the students could also choose the challenge they wished to work on, the chosen challenge often guided their choice of location and group size. For example, the *Coaster Boss* and *Solar Roller* challenges took up plenty of space, so students often worked in the corridor on those challenges. *Dream Home* and *Ringtones* did not require any extra materials or space, so students often worked in the computer lab.

Data Analysis

The video data were transcribed and analysed using interaction analysis methods that took into account of verbal, visual and material conduct (Jordan & Henderson, 1995). The data were approached inductively by first approaching the video corpus as a whole and then focusing on selected events in greater depth (Derry et al., 2010). In particular, we were interested in those moments in the video data that gave concrete evidence of the intra-actions between the students, teachers and material objects of the FUSE Studio makerspace in the sociocultural context of the school.

Findings

Next, we turn to illuminating the ways in which the materiality was entangled and mediated the communication among students and their teachers in the educational makerspace, creating opportunities and tensions. The examples show how the material objects of the makerspace were transformed into social objects in the material-discursive spaces of communication, the activity being primarily *about* the objects (Examples 1–2), *around* the objects (Examples 3–4) and *with* the objects (Examples 5–6). At the same time, each example also demonstrates the ways in which different voices stemming from the socio-material context were enacted with opportunities and tensions for teaching and learning according to the ideals

advocated by maker education as well as the normative expectations of the formal school context.

Example 1: 'Saving on Ringtones does not work.'

Our first example pictures a material-dialogic space of communication *about* the material object itself. Here, the materiality itself is at the centre and is the topic of communication. According to the teacher interviews, the malfunctioning of the technical infrastructure of the FUSE Studio was typical, especially during the first year of its implementation. In these communication situations, there was often a shift in the meaning of the technology for the ongoing activity from implicit mediation of the material object into a more explicit mode. In the example below, the voice of the teacher who instructs the students about the malfunctioning of the technology is dominant. There is little evidence of the students' voices of initiation, agency or creativity as advocated by maker education.

1. Teacher Bill: Hey, if you're doing that ringtone, then try to get it in good shape today because saving it doesn't work.
2. Student 1/Marika: Okay.
3. Teacher Bill: So, it could be a good goal to get it, get this one level finished today.
4. Student 2/Leena: Okay. Should we try?
5. Teacher: Bill Mm. Because saving doesn't work right now.
6. Student 1/Marika + Student 2/Leena: Okay, yeah.
7. Teacher Bill: It's a little… You have to start again next time if you don't finish.

The excerpt begins when the teacher Bill notices that saving audio files does not work on the *Ringtones* software. Two groups of two girls are working on the challenge and the teacher informs both of them about the malfunction. Although the technical issue is not ideal, the teacher

attempts to turn the situation into a motivational factor by asking the students to work hard so that they could complete the whole level of the design challenge in one session (lines 3, 7). Here, the material-dialogic space is embedded in procedural communication with little reflection and negotiation. Through the teacher's interpretation of its meaning, the technological failure also contributed to the conditions of the social activity of the students, adding a sense of urgency to complete the task in less time than usual.

Example 2: 'Hey, what's this "hole thing"?'

Example 2 illuminates communication where the students are wondering and experimenting *about* the use and functioning of FUSE Studio design software, supported by the teacher. The example demonstrates the students' sense making about the material objects in the educational makerspace. Here, it becomes clear how learning to use the advanced technological tools of the educational makerspace is pivotal for gaining access and authority in making activities in this space. Here, the explicit mediation of the material object of teaching and learning activities is very visible.

1. Student 1/Mel: Hey, what is this 'hole thing'?
2. Teacher Sam: What thing?
3. Student 1/Mel: Hole. That hole.
4. Teacher Sam: Yeah you're supposed to make a hole there.
5. Student 1/Mel: What hole?
6. Teacher: Sam Or what?
7. Student 1/Mel: No, I mean what is that hole?
8. Student 2/Anne: Yeah, what does it do?

9. Teacher Sam: Is it that it turns transparent for a while so you can… Click on it again so it goes into the hole-mode. [girl clicks]

10. Teacher Sam: Yeah, so it shows that you can, it turns transparent so you can see through it. If you have that kind of situation that your planning requires you to be able to look through it.

11. Student 1/Mel: What do we do now that we're ready?

12. Student 2/Anne: We should probably look at the video.

13. Teacher Sam: Look at the directions, I can't remember by heart.

14. Student 1/Mel: You're guiding it now Anne, I can't be using that thing [the laptop] the whole time.

15. Student 2/Anne: Okay. So, let's continue. [clicks open the directions video on the website]

16. Student 1/Mel: This is so slow… We have done that already.

17. Student 2/Anne: Okay, new video. [girls continue watching, teacher leaves]

In this example, two girls Mel and Anne are sharing a laptop and working together on a design challenge called the *Keychain Customizer*. They are designing a model of a keychain but are unsure of the software *Tinkercad's* commands. For that reason, they ask for the teacher's help. The teacher Sam suggests that they try out the hole-command (line 9), but he does not demonstrate using the command himself; instead, he encourages the students to do it. Then, the teacher explains what the command does and why one might use it (line 10). When the students ask what to do next, the teacher guides the students to look at the directions (line 13), like Anne had suggested (line 12). By asking the students to do so, the teacher confirms a practice typically advocated by maker education that students should try to use other resources among themselves

before asking for a teacher's help (Stevens & Jona, 2017). Consequently, the material-dialogical space of the students' joint activity is expanded to involve the set of resources found in the website to support the students' independent engagement with the challenges and the associated technology. Therefore, the teacher points to the rules of the task and refocuses the students on it. This makes Mel assign the computer turn to Anne (line 14) who agrees (line 15). When Mel and Anne start looking for the directions, the teacher stays and listens to their discussion. When they are refocused on the task, the teacher leaves.

Example 3: The Stickiness of Artefacts

Insert Figure 2 here

Figure 2. 3D-printer as a magic machine

Our analysis of the data reveals that often times the material artefacts of the educational makerspace functioned as a 'glue' that brought both the students and teachers together *around* the materials to observe, wonder, discuss and/or share, as demonstrated in Figure 2. At times, these material-discursive spaces of communication were filled with silence with everyone intensively observing what was happening while the technology (such as 3D printer) or a human (a student or teacher) constructed or developed something. We could also identify conversations about the matter and its meaning situated in the present, the students explaining what was happening or giving instructions about alternative ways of working or using other material objects than those available in the makerspace. Excitement, interest and emotional engagement in general were made visible by non-verbal and verbal communication in the material-dialogic spaces around social objects. At times, the conversation travelled beyond the present across time and space while the students shared stories, experiences and knowledge from their lives in the socio-material context of the makerspace.

Example 4: Messing around with Artefacts

Example 4 illuminates an alternative or, in fact, a competing material-dialogic space of communication constructed in the educational makerspace. Here, the students were engaged in another activity that they found more meaningful instead of working on a design challenge. That is, they were playing *around* a mobile game with their mobile phones.

[teacher walks into hallway to check on boys]

1. Student 1/Pekka: They're just playing…
2. Teacher Greg: Hey, what game do you have going on here?
3. Student 1/ Pekka: They're playing *Clash Royale*…
4. Teacher Greg: Hey, put *Clash Royale* in your pocket and put your games away.

In this example, the teacher walks into the hallway where a group of boys are working on a *Coaster Boss* design challenge. One of the students Pekka in the group responds immediately to the teacher's presence by explaining why their work is not coming along (line 1). The teacher takes a strong stance with his hands on his waist, which can also be interpreted as a nonverbal sign of authority, as he asks the students to stop playing the game (line 4). The students obey the teacher's request and continue working on the FUSE design challenge. Overall, this example demonstrates the co-presence of at least two material-dialogic spaces that are performed in parallel, that is, working on the design challenge and playing the students' own digital game. The co-presence of multiple material-dialogic spaces is enhanced by the fact that the online world and students' mobile phones are also commonly used in the FUSE Studio makerspace for the design challenge activities and their documentation. The teacher's actions in the example can be seen as an attempt to contain and constrain the dialogical-material space of the students' activity. The example also demonstrates how digital tools define and alter the nature of the material-

dialogic spaces, and ask for the students' accountable agency to follow the expectations for their activity.

Example 5: Making a Dream Home

Example 5 demonstrates how the materiality of the educational makerspace functioned as an explicit mediational means to explain *with*. In this example, the students are working on the *Dream Home* design challenge.

1. Student 1/Tara: I would like to turn this so I cab get to the other side.
2. Student 2/Hanna: Me too, because I don't even know how to get there.
3. Teacher John: Well wait, let's see who is furthest along in *Dream Home*. Eric and Ian, have you rotated the angles there so you can get to the other side of the house?
4. Student 3/Rick: I have!
5. Teacher Greg: Hold down the mouse's button and then spin.
6. Teacher John: Okay, Rick can come instruct.
7. Student 3/Rick: [comes over to the girls] What?
8. Student 2/Hanna: How on earth do you turn this?
9. Teacher John: Hold down the mouse and…
10. Student 3/Rick: What did you want to do?
11. Student 1/Tara: Rotate the angle.
12. Student 3/Rick: Take that and then… [Tara rotates]
13. Teacher John: Which one was it, Rick? Why don't you show me too.
14. Student 3/Rick: This tool.
15. Teacher John: Oh!

Here, Tara and Hanna have asked the teacher for help with rotating the view so they can see the whole house. The teacher's first response is to find other students to help (line 3). By asking other students to help, the teacher is encouraging relative expertise in which the students can act as experts on the challenges. Student Rick is eager to help and comes over to advise the girls. After this, the teacher asks Rick to show him how to do it as well (line 13). By doing so, the teacher indicates that it is acceptable that teachers do not always know what to do in all of the challenges. He also reinforces Rick as an expert of the challenge. Interestingly, teacher Greg exclaims the instructions in the middle of the conversation (line 5), even though he is helping other students at the time. Greg is probably aiming to speed the helping process, but this is in conflict with the other teacher's intervention strategy and that of the pedagogical model of the FUSE Studio makerspace that advocates for relative expertise. Teacher John does repeat these instructions partially (line 9) but then lets student Rick to help and explain it to the two girls.

Example 6: Transforming the Material Confounds

In our final example, we illuminate how a tension between the students' interest and the material requirements of the makerspace triggered a productive material-dialogic space that took the students' maker activity beyond the given design challenge. Here, the teacher's interpretation of the challenge was instrumental in transforming the learning activity into a meaningful one for the students and in facilitating a material-dialogic space for joint problem solving between himself and the students. This example also makes visible improvisations and overcoming obstacles inscribed in the material whilst communicating and making joint meaning *with* the material artefact.

1. Student 1/Anton: What should I do now? I want to do a wristband and then to 3D print it. [It is on his computer. The teacher approaches him and stands beside him with a hand

on her jaw.]

2. Teacher Beth: But like [chuckles], the challenge is that at this first level, you must do some simple earring models.

3. Student 1/Anton: Do I have to do the earring model?

4. Teacher Beth: Yes. At level one and they are done in 2D, which means that they are done as though you designed them on paper and cut them and look at what they could be like. It has the idea that you perceive what the size is, so that when you start to draw bigger things or something else so that you know which is about the size [waves her hands in circles], like around which you move about. I mean in these instructions it is like you draw some earrings on paper, you cut them and then you see if it is really a good size, can you move it a bit down-then [in reduced voice]. Wait here; you have to watch the video because I am not sure what it means.

5. Student 1/Anton: I will wait until Mike [student 2] comes, I will do it with him, but is it obligatory to make an earring?

6. Teacher Beth: Um, well, like this is the order to get to the next level. So, you should, this, but you can, wait, it does not necessarily have to be. What else could it be apart from earrings?

7. Student 2/Mike: A finger thing!

8. Teacher Beth: Yes, for example [to Anton]. Did you hear this?

9. Student 1/Anton: Yes!

10. Teacher Beth: Because it is about the same size like the earring. So, the idea is that you measure it. Because after it you will do the digital modelling. The finger thing probably works as well as an earring."

In this example, Anton wants to start working on *Jewellery Designer* (a FUSE Level 1 challenge). He asks the teacher Beth for help (lines 1-3). Mike is standing behind Anton and wants to know what Anton is going to do. Anton explains that he is going to design a wristband and print it out with the 3D printer when it arrives. The instructions for the challenge are in English, and the teacher translates the instructions for Anton (line 4). These instructions ask the student to design a simple earring. Anton expresses that he does not want to design earrings and asks the teacher if he can design something else (line 5). The teacher replies that in this level of the design challenge, he is supposed to design earrings so that he can begin to understand the role of the size of a product in the design process. The teacher then wonders out loud if Anton could nevertheless design something else the same size as an earring. Mike suggests that Kasper could design a 'finger thing' (line 7), and the teacher agrees, because a 'finger thing' is about the same size. The teacher again highlights that the idea is to measure the design (line 10).

Anton's personal interest to create a wristband and the requirements built into the maker design challenge (to create earrings) did not match and thus created tension. The vignette demonstrates how the educational makerspace with its aim of promoting interest-driven learning, can turn into traditional classroom activity in which the student has to follow tasks and instructions embedded in the material with no opportunities for creative deviations from the plan. In this case, a productive resolution was reached, with the teacher and another student, Mike, coming up with an alternative design idea that nevertheless met the learning goals set for the task. The fulfilment of Anton's interest was reached in a material-dialogic space in which the voice of the student and teacher were given authority. Here, the teacher's interpretation of the task is instrumental, in the sense that the teacher interprets the task not as being specifically about designing an earring (but more broadly, as being about designing a small item (i.e.,

acquiring expertise in the design process). The tension and its improvisational resolution led Anton to engage in a maker activity he found meaningful, and it also transformed the activity setting.

Discussion

In this chapter, we have contributed to current theorising and empirical research on the role and meaning of materiality in a novel educational makerspace. We have argued that this knowledge is pivotal for understanding and supporting communication and learning in a makerspace environment where the students independently navigate and integrate knowledge from different resources and domains using a range of material artefacts during their design and making activities (see also Ludvigsen, 2009). To further the field, we drew upon the concepts of 'social objects' and 'material-dialogic space' to explain how material artefacts can become socialised in ongoing communication among students and teachers while they engage in design and making activities. Namely, we illuminated how students, teachers *and* materials enact together and enable particular teaching and learning phenomena to emerge, with opportunities and tensions. We hold that this knowledge can potentially drive future understanding and development of educational spaces, their materialities, as well as enhancing teaching and learning opportunities in educational makerspaces and beyond. Recent research also underlines the importance of this knowledge, indicating that teachers are often unaware of the meaning and role of materiality in and for their teaching (Hetherington & Wegerif, 2018).

Our study makes visible how the materialities of the educational makerspace are an important part of the communication and meaning-making processes among students and teachers, supporting and challenging ongoing teaching and learning activities. The study demonstrates the nuanced ways in which material artefacts are transformed into social objects in

the material-dialogic spaces of communication. It also suggests how the practices, rules and values of the socio-historical context of the school and those of the novel educational makerspace, and the historicities of the participants themselves are a pivotal part of the ongoing communication, mediating the nature of teaching and learning phenomena in situ (see also Kumpulainen, Kajamaa, & Rajala, 2018; Rasmussen, Amundrud, & Ludvigsen, this volume).

Our study reveals three distinct, yet often overlapping ways in which the material objects of the educational makerspace become socialised in the students' and teachers' communication processes in the educational makerspace. Namely, *about* (i.e., centred on material objects); *around* (i.e., in the context of material objects) and *with* (i.e., constituted with the material objects) artefacts. First, we identified material-dialogic spaces of communication in which the primary activity was *about* the material objects themselves. This mode of relating to material objects became evident especially when the habitual ways of engagement were disrupted for example by technological failures or discrepancy between the means and ends of the activity (see also Dewey, 1933). The problems in the technological infrastructure also created uncertainty among the teachers and challenged their role as authority as they did not always have control over the material objects themselves either.

Second, we identified material-dialogic spaces of communication in which the primary activity took place *around* the material objects. Our analysis suggests that the contemporary pedagogical and digital infrastructure engender dynamically shifting and expansive material-dialogic spaces. For example, the group configurations in the FUSE Studio makerspace are flexible and the students are invited to work across groups to help other students. Similarly, digital tools offer vast possibilities for expanding the scope of the activity and dialogue. This

imposes difficulties for teachers whose institutional task is traditionally to contain and at times also constrain the students' activity.

Third, we depicted activity and communication among the students and teachers that was primarily about working and making meaning *with* the material objects. Here, the material artefacts played an important role as semiotic tools to communicate and establish joint meaning. At times, this also led to improvisation and creativity among the teachers and students in finding alternative ways to design and make.

Altogether, these three positions of material artefacts in the students' and their teachers' communication demonstrate an active and intertwined interplay between explicit and implicit mediation. In fact, our findings imply that the borderline between these two forms of mediation is very blurred and shifting in the material-dialogic spaces performed in the educational makerspace. Our study also reveals a dynamic inter-animation of different voices emerging in the intra-actions of the students, teachers, and materialities of the educational makerspace embedded in the sociocultural contexts of the school. The interanimation of voices that were performed into being in the material-dialogic spaces of the educational makerspace evidence delicate and at times strong power relationships in the positioning of different voices, with consequences for teaching and learning. As our empirical examples show, at times, the voices of the materiality dominated the communication, undermining the voices of others. At other times, it was the teacher's voice that become more authoritative than other voices, with opportunities and tensions for student-centred learning. We also depicted material-dialogic spaces of communication that demonstrate joint reasoning and meaning making between the students and teachers, giving rise to relative expertise and enhancing the students' interest-driven creative activities.

Our research also points out how materiality is an important mediator of power and educational equity, making materiality a pivotal research focus for future studies in education. In our research, not all the students were found to engage in interest-driven STEAM learning activities in the educational makerspace despite free choice of the design challenges they could work on. Instead, they found their own mobile games more compelling. Our observations resonate with existing research that points out how makerspaces hosted by various educational and cultural institutions often fail to attract and engage the broader population of young people in learning due to culturally-biased materialities and activities (Barton, Tan, & Greenberg, 2016; Peppler et al., 2016). Our research echoes these concerns and calls for the quality and inclusivity of makerspaces and their materialities, and urges further investigation into novel, material-rich educational spaces as they are related to creating democratic, equitable and deep learning experiences for diverse students.

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Figure 1. Students working on the FUSE Studio maker challenges

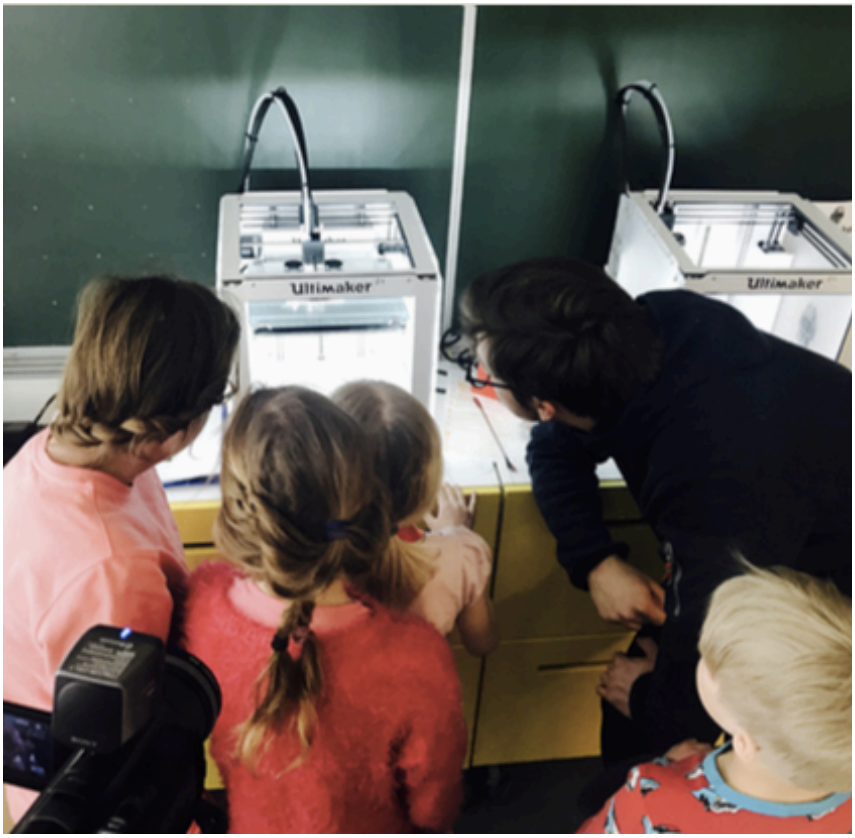

Figure 2. 3D printer as a magic machine